National Aeronautics and Space Administration

GRX-810 and the future of AM-enabled high-temperature propulsion

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9 June 2026

METAL AM
WEBINAR

Starting soon...

LIVE WITH NASA:
GRX-810 and the future of AM-enabled high-temperature propulsion

Thanks to Linde Advanced Material Technologies, our webinar sponsor and NASA GRX-810 licensee

Why this alloy, why now?

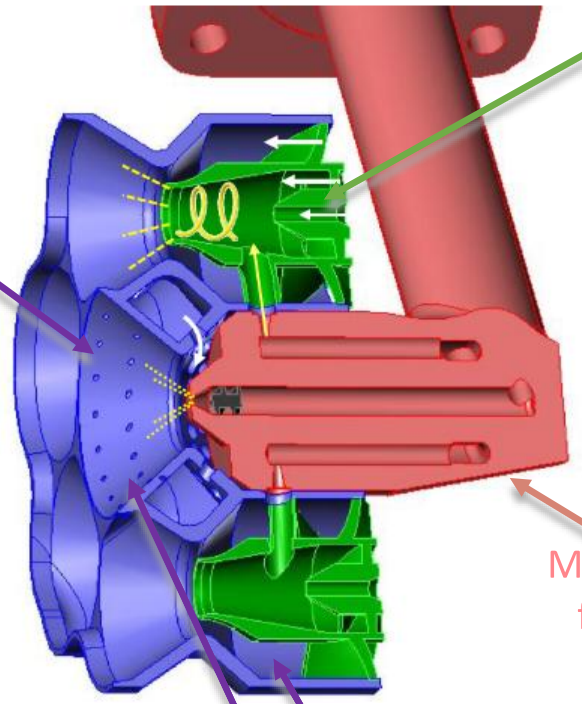
Background – Application

Problem: Conventional materials and processing techniques limit the design of combustor domes used in jet turbine engines.

Proposed Solution: Develop a high ductility, high temperature material for an additively-manufactured (AM) combustor fuel nozzle and dome for supersonic aircraft (>1093°C (2000°F) operating temperature).

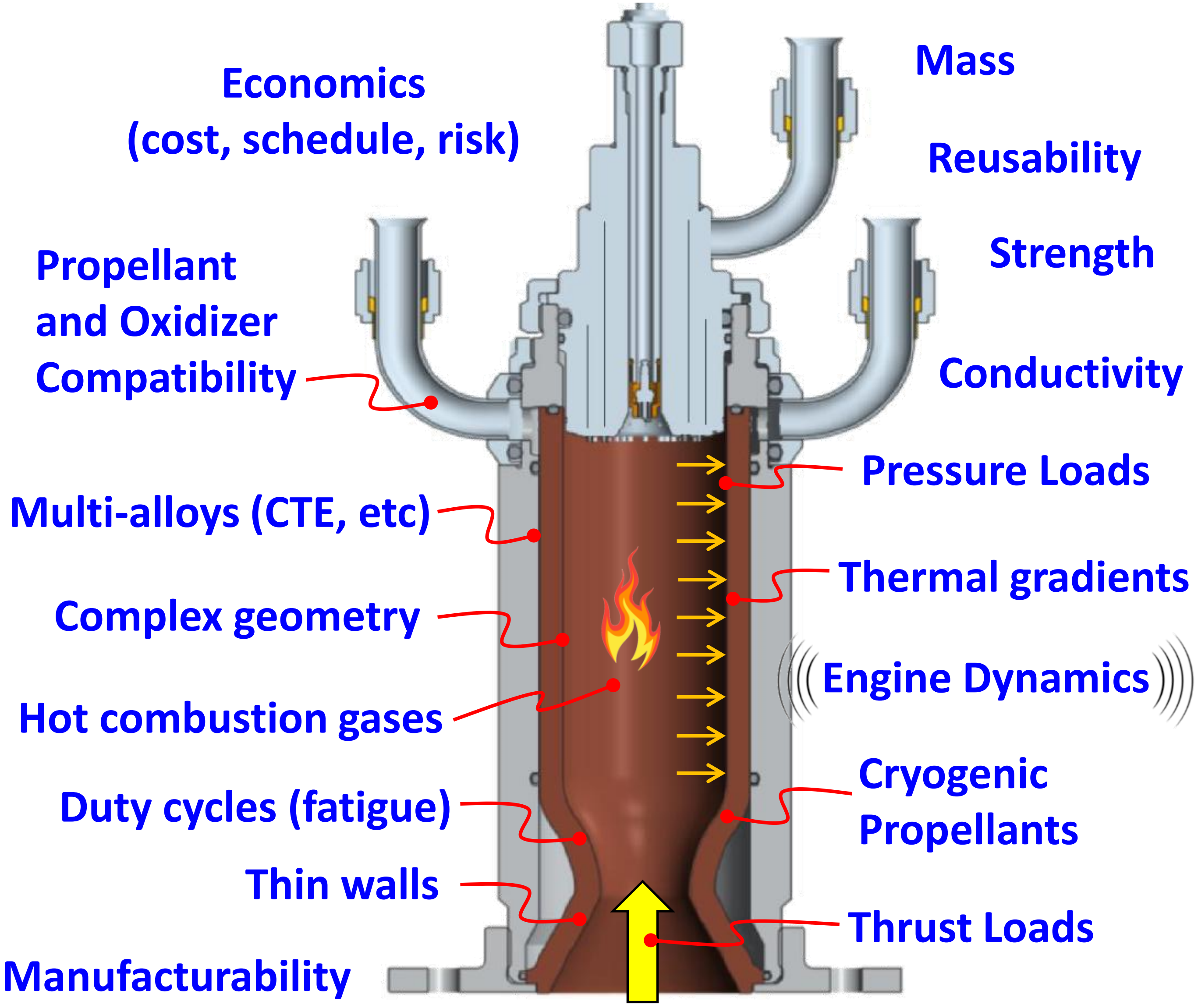
- Lead to several improvements to the turbine combustor design ultimately reducing NOx pollution and lowering weight.

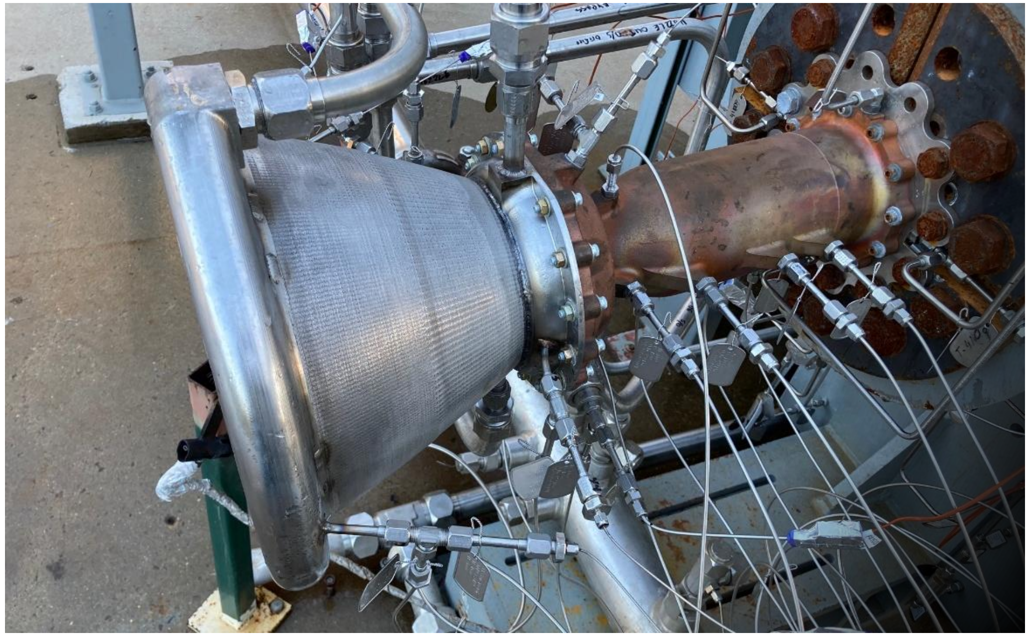
- May enable lean-front-end small-core combustors.



Schematic of AM produced fuel injector/combustor dome

Example: Combustion Chamber Material Considerations





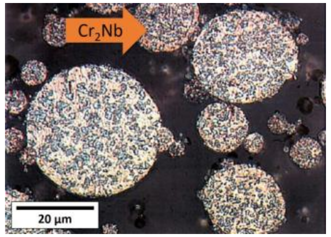
What is NASA’s history with additive?

Maturity of Metal AM for NASA Applications

LASER POWDER BED FUSION

DIRECTED ENERGY DEPOSITION

Case Study and Timeline of GRCop-42

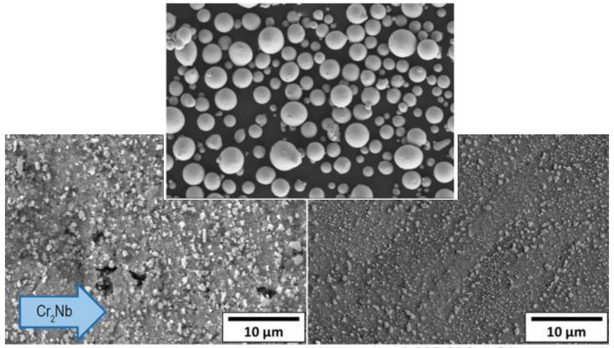


GRCop Developed

1987

1990s

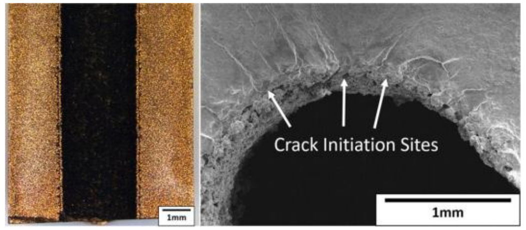
2000

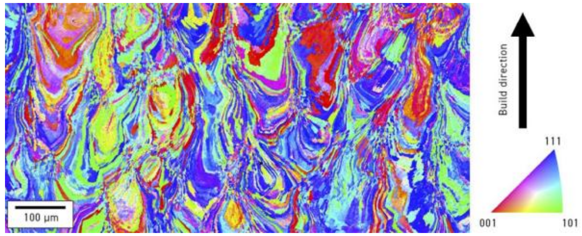


Extruded GRCop-84 L-PBF GRCop-84

2012

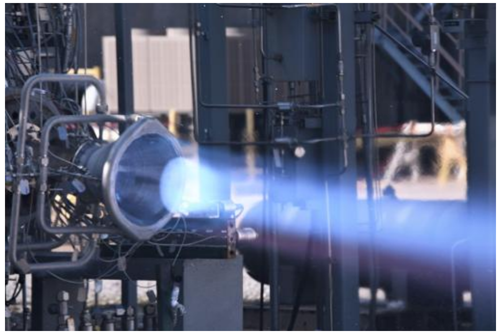
2015





2018

2019

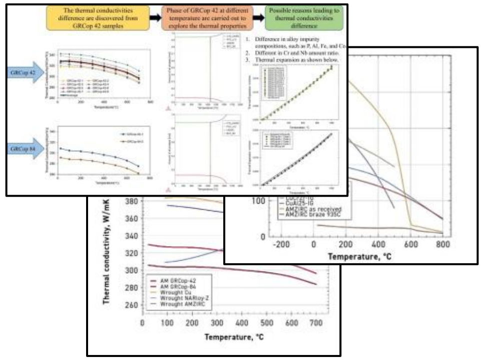


2020

2021

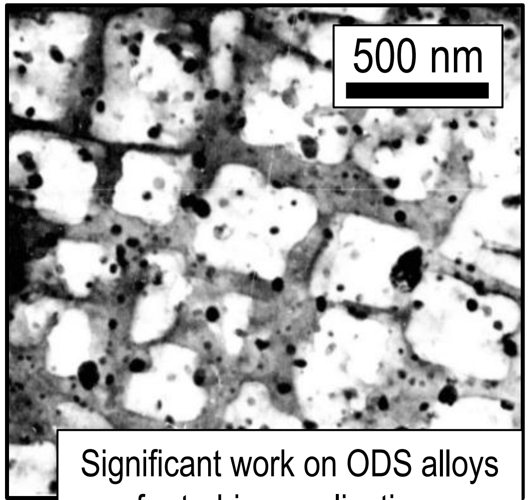
2023

2024

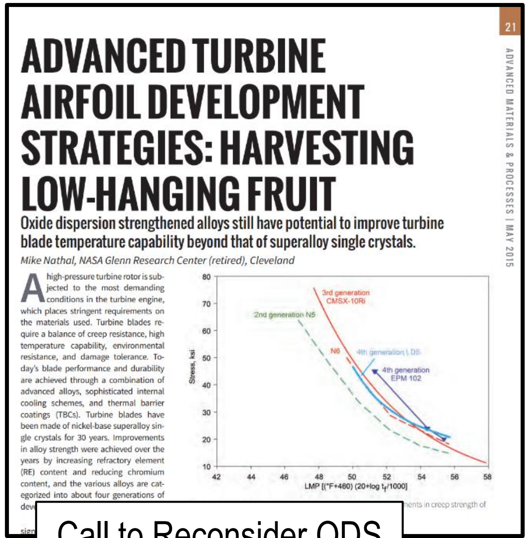


2025

What makes GRX-810 so unique?



Significant work on ODS alloys for turbine applications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ADVANCED MATERIALS & PROCESSES | MAY 2015

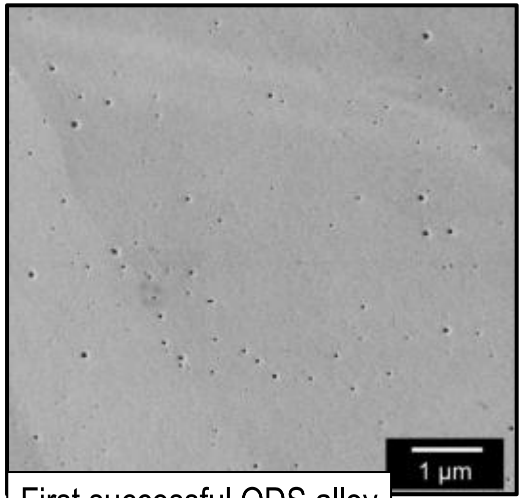
ADVANCED TURBINE AIRFOIL DEVELOPMENT STRATEGIES: HARVESTING LOW-HANGING FRUIT

Oxide dispersion strengthened alloys still have potential to improve turbine blade temperature capability beyond that of superalloy single crystals.

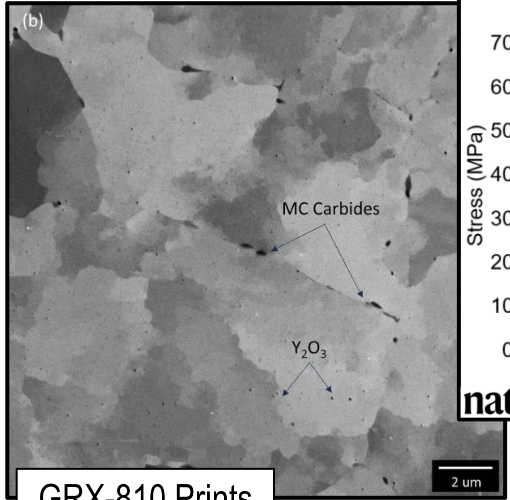
Mike Nathal, NASA Glenn Research Center (retired), Cleveland

A high-pressure turbine rotor is subjected to the most demanding conditions in the turbine engine, which places stringent requirements on the materials used. Turbine blades require a balance of creep resistance, high temperature capability, environmental resistance, and damage tolerance. Today's blade performance and durability are achieved through a combination of advanced alloys, sophisticated internal cooling schemes, and thermal barrier coatings (TBCs). Turbine blades have been made of nickel-base superalloy single crystals for 30 years. Improvements in alloy strength were achieved over the years by increasing refractory element (RE) content and reducing chromium content, and the various alloys are categorized into about four generations of

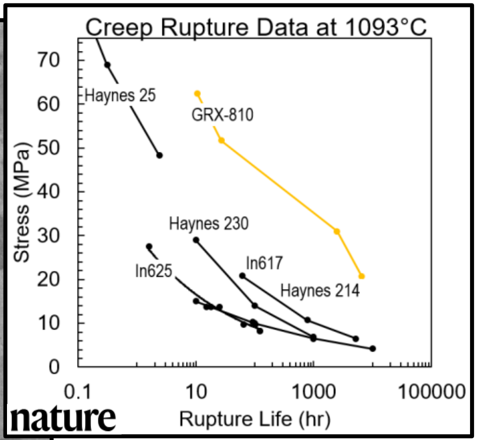
Call to Reconsider ODS



First successful ODS alloy

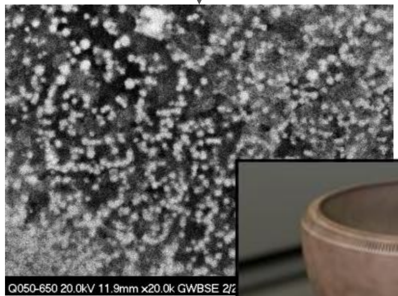


GRX-810 Prints



GRX-810 Publication

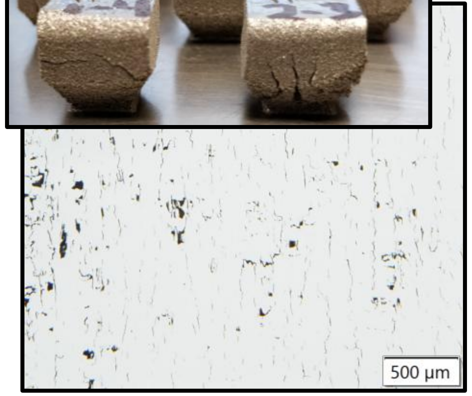
1970 | 1980 | 1990 | 2000 | // | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023



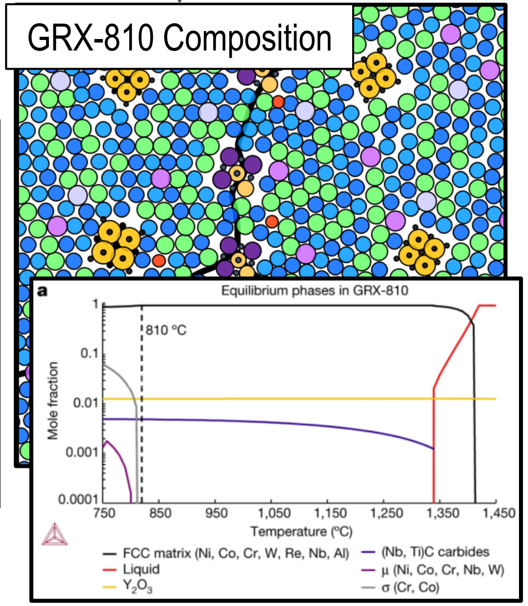
Fine Cr_2Nb Dispersoids

GRCop Rocket Chambers

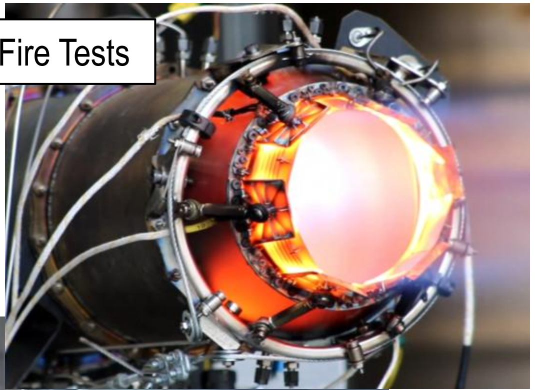
First AM ODS attempts



GRX-810 Composition



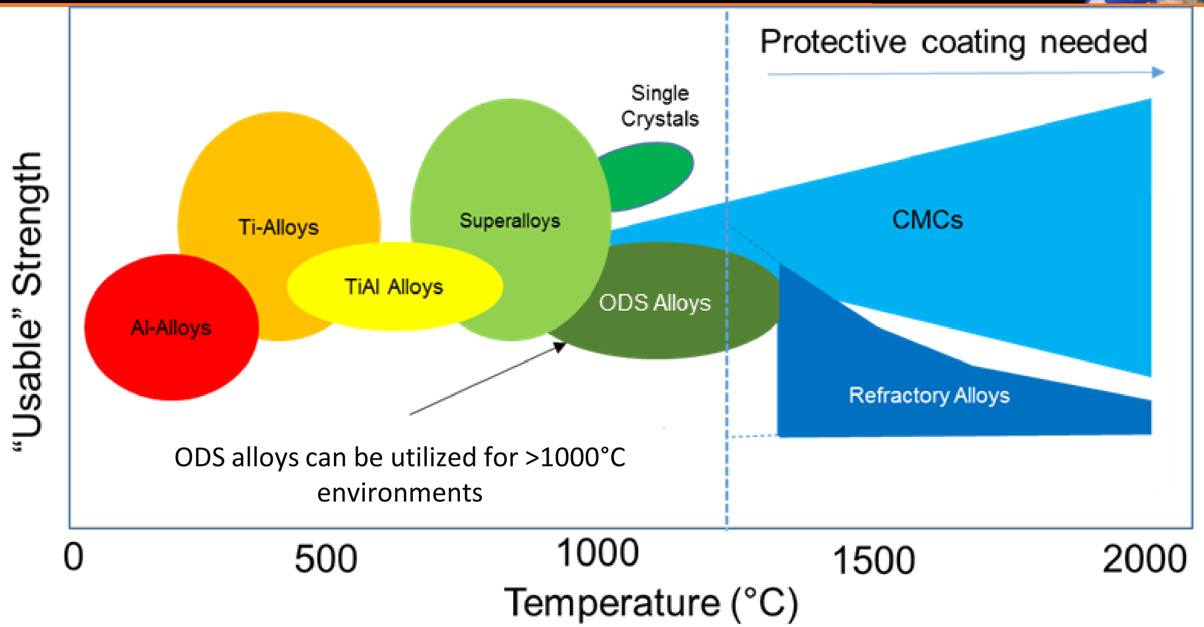
GRX-810 Hot Fire Tests



High Temperature AM Compatible Materials

High Temperature Materials:

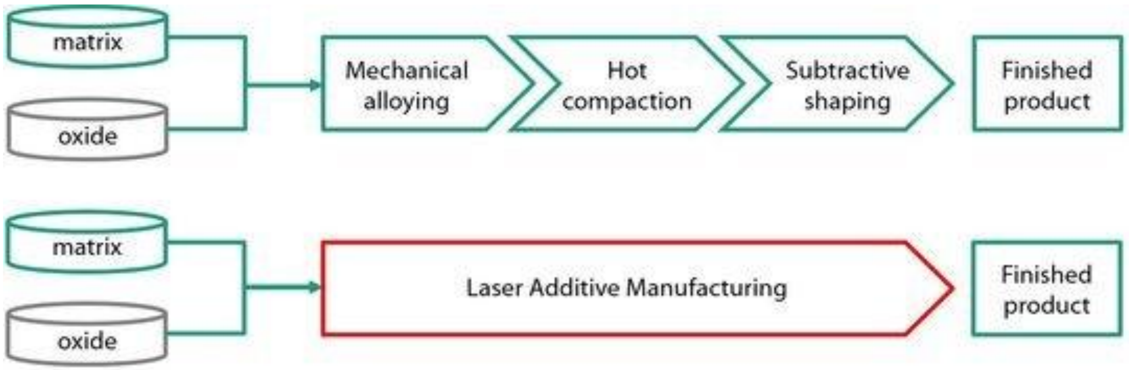
- Refractory metals
- Carbon-Carbon composites
- CMC’s
- Ni-base superalloys
- Oxide dispersion strengthened (ODS) alloys



Inspired by Andy Jones. ODS alloy Development.

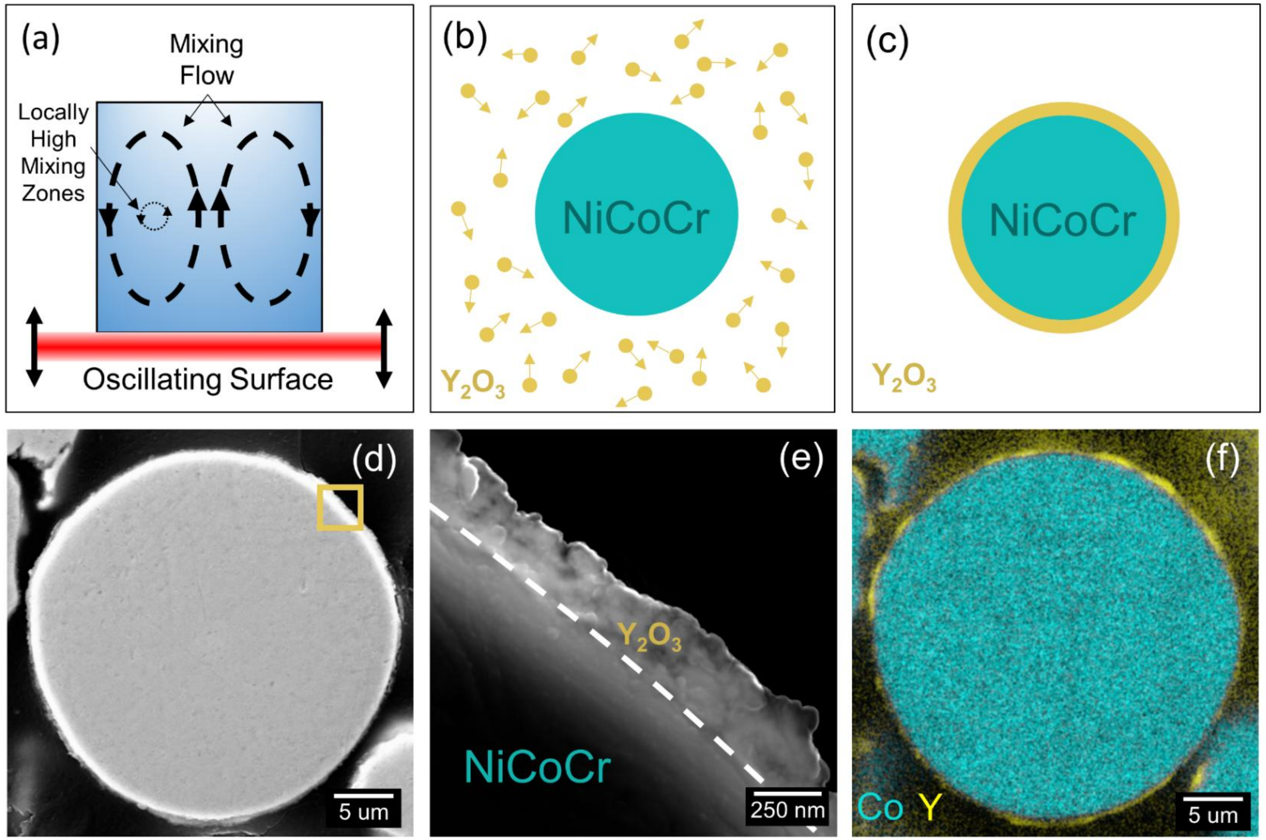
(ODS) alloys offer higher temperature capabilities compared to Ni-base superalloys. However, it has been a challenge to produce ODS alloys through conventional manufacturing methods.

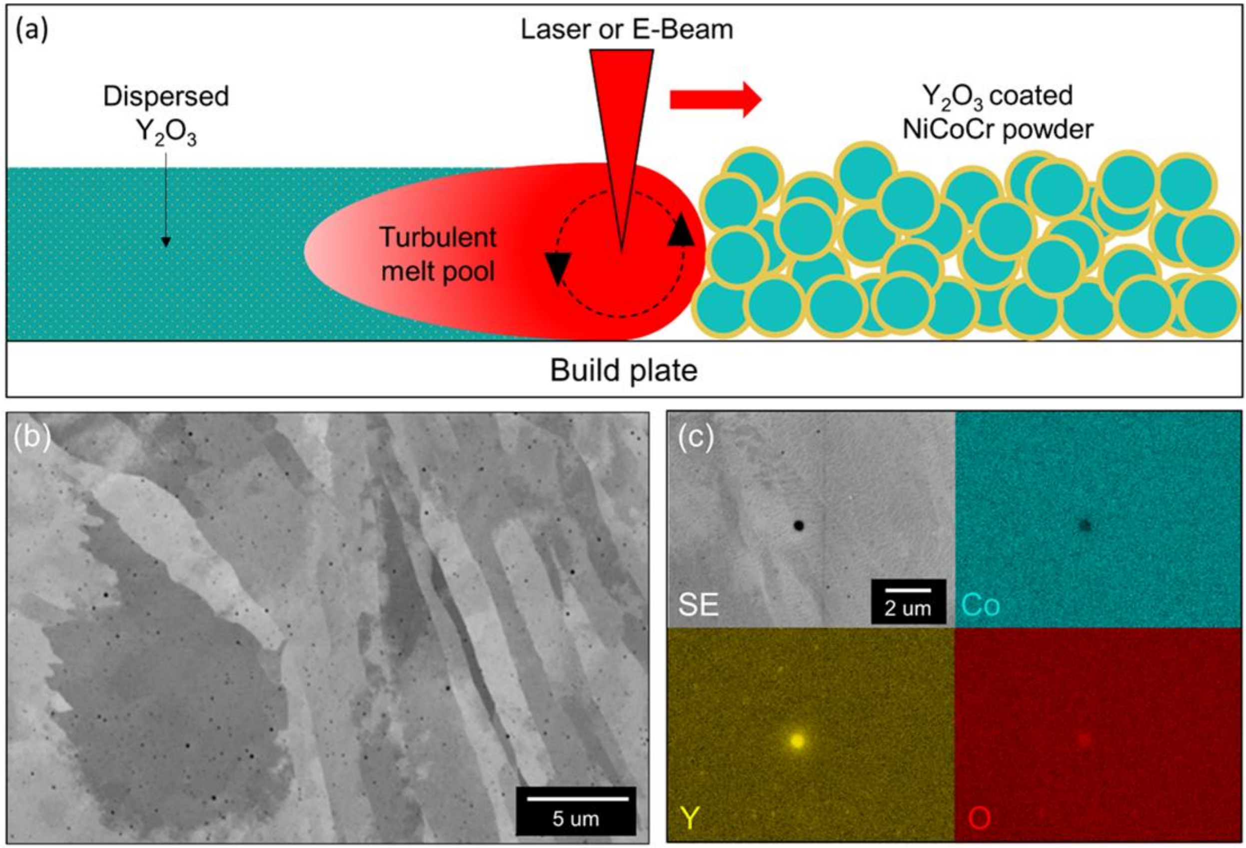
Conventional Manufacturing vs AM



Can AM improve ODS alloy manufacturability?

Leveraging L-PBF to Produce Oxide Dispersion Strengthened Alloys





- New high energy mixing technique successfully coats metal powders with nano Y_2O_3 particles.
- The coating technique does not affect the printability of the powder unlike mechanical alloying.
- L-PBF successfully disperses the nano-scale Y_2O_3 particles throughout the AM build.
- The coating + printing technique successfully produced an ODS alloy without the use of mechanical alloying

Development of the GRX-810 Composition

Model Driven MPEA Design

Goals to improve on previous NiCoCr Entropy Alloy:
1.) Maximize solid solution strengthening
2.) Maintain solid solution matrix
3.) Add grain boundary carbides
4.) Reduce freezing range to under 100°C for printability
5.) Avoid TCP and intermetallic grain boundary phases

<u>$>10^7$ equilibrium calculations provided an optimized composition named GRX-810</u>

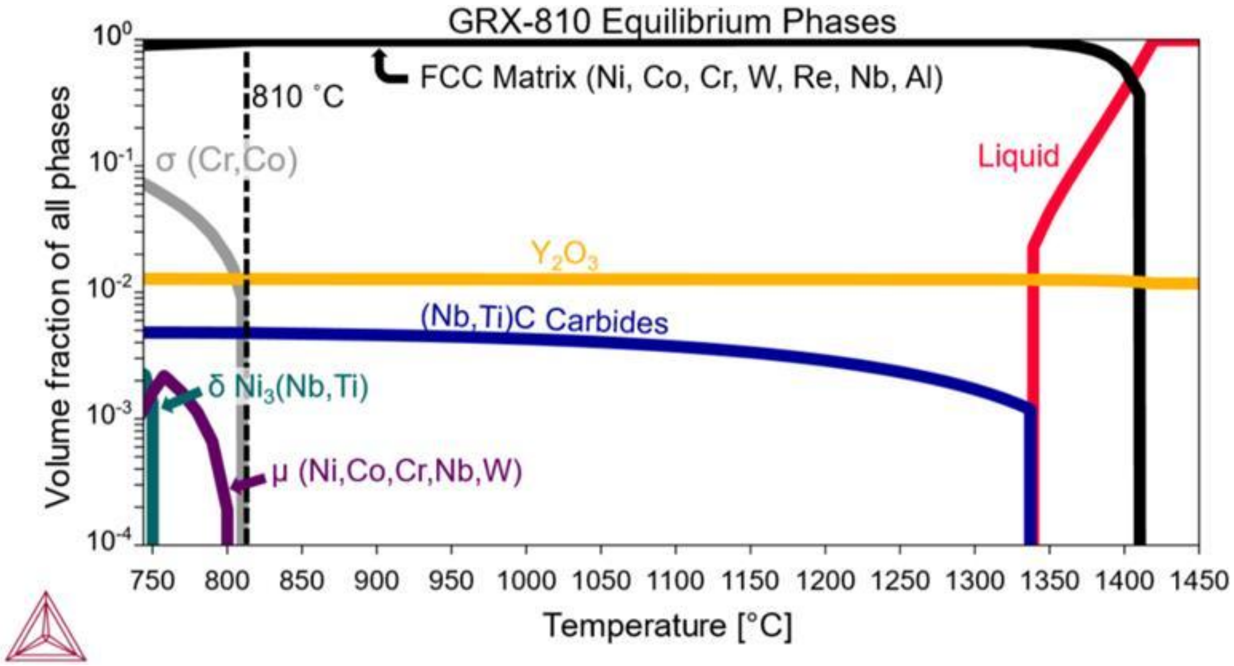


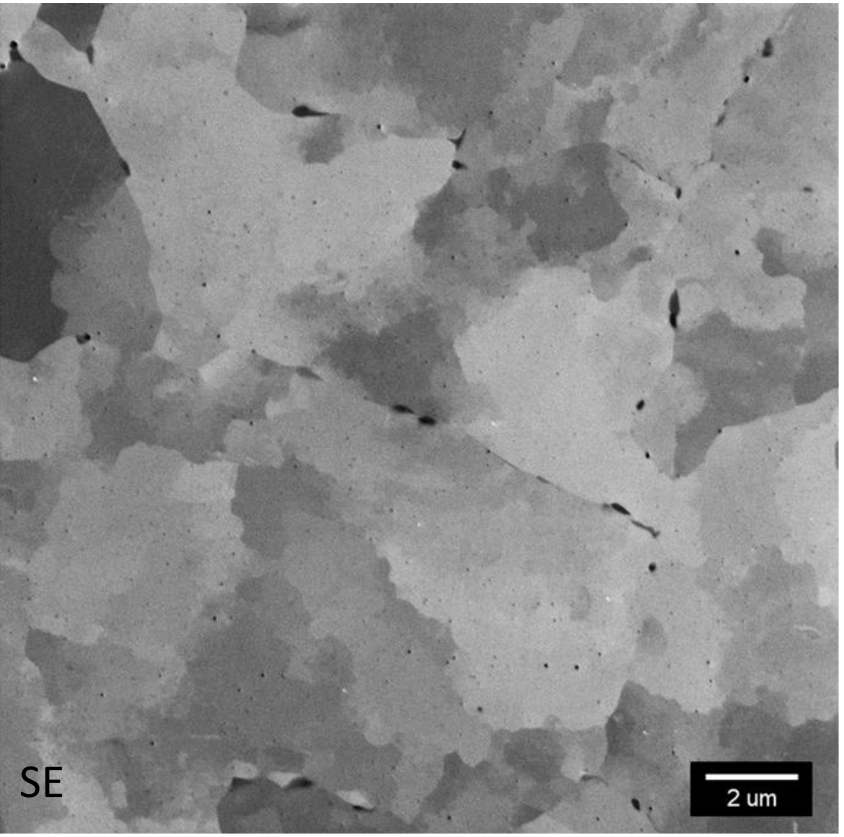
Figure: CALPHAD simulation of phase formation in new composition. No intermetallic or TCP phases are predicted.

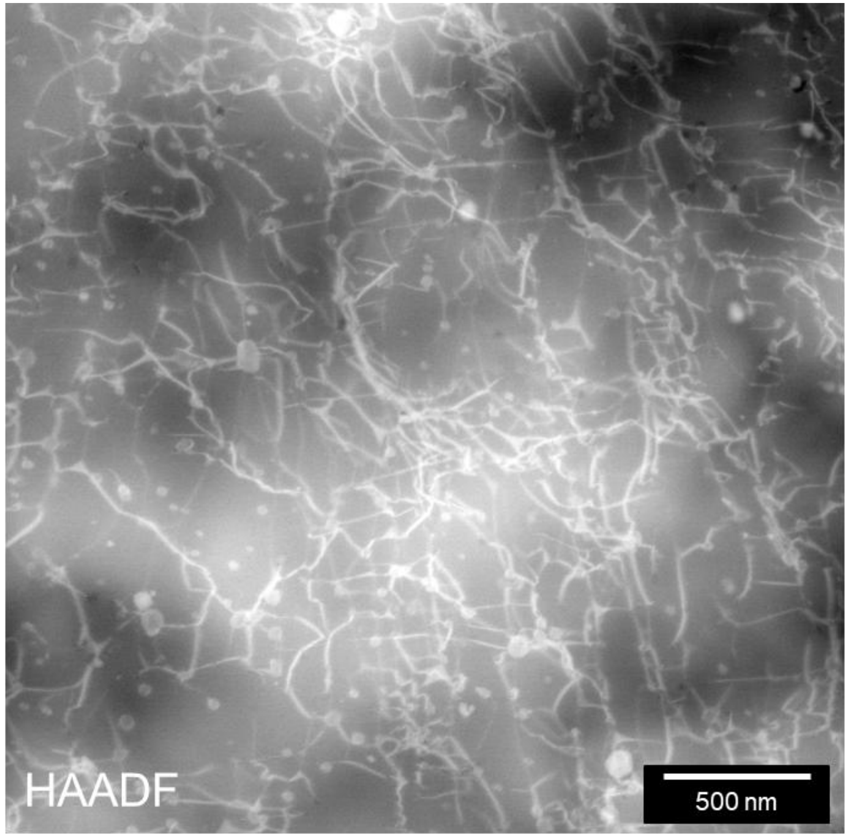
	Ni	Co	Cr	Re	Al	Ti	Nb	Mo	W	Zr	C	B
Nominal Composition (GRX-810)	Bal.	33	29	1.5	0.3	0.25	0.75	0	3	0	0.05	0

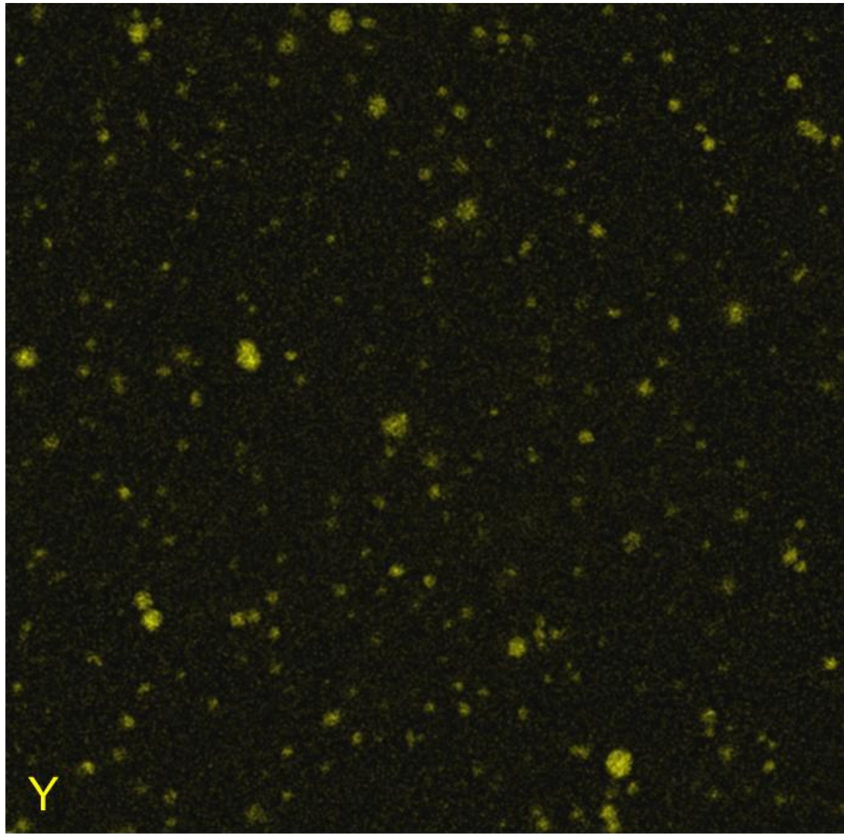
Simulations developed by C. Kantzos

Did GRX-810 pass the test?

GRX-810 Microstructure



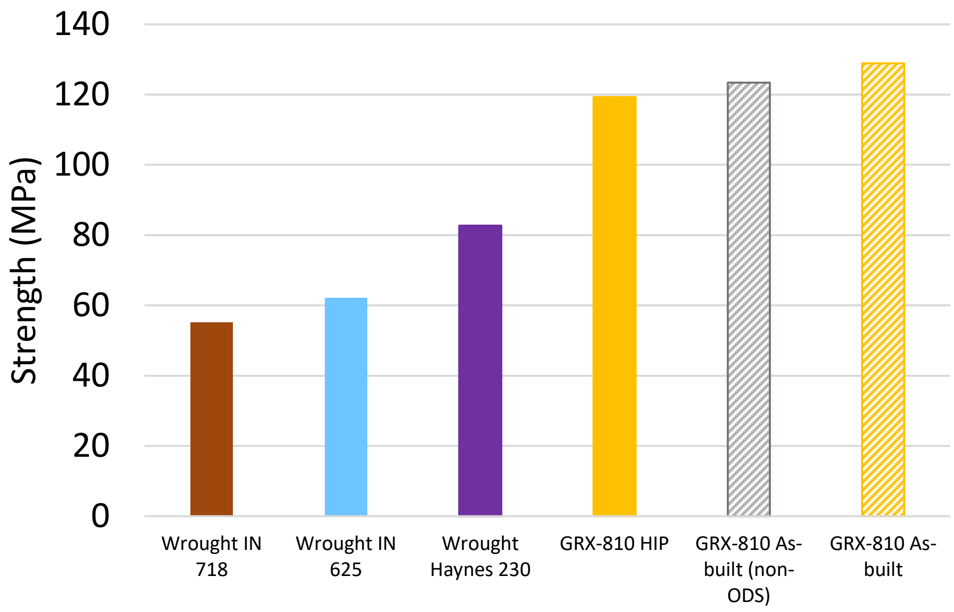




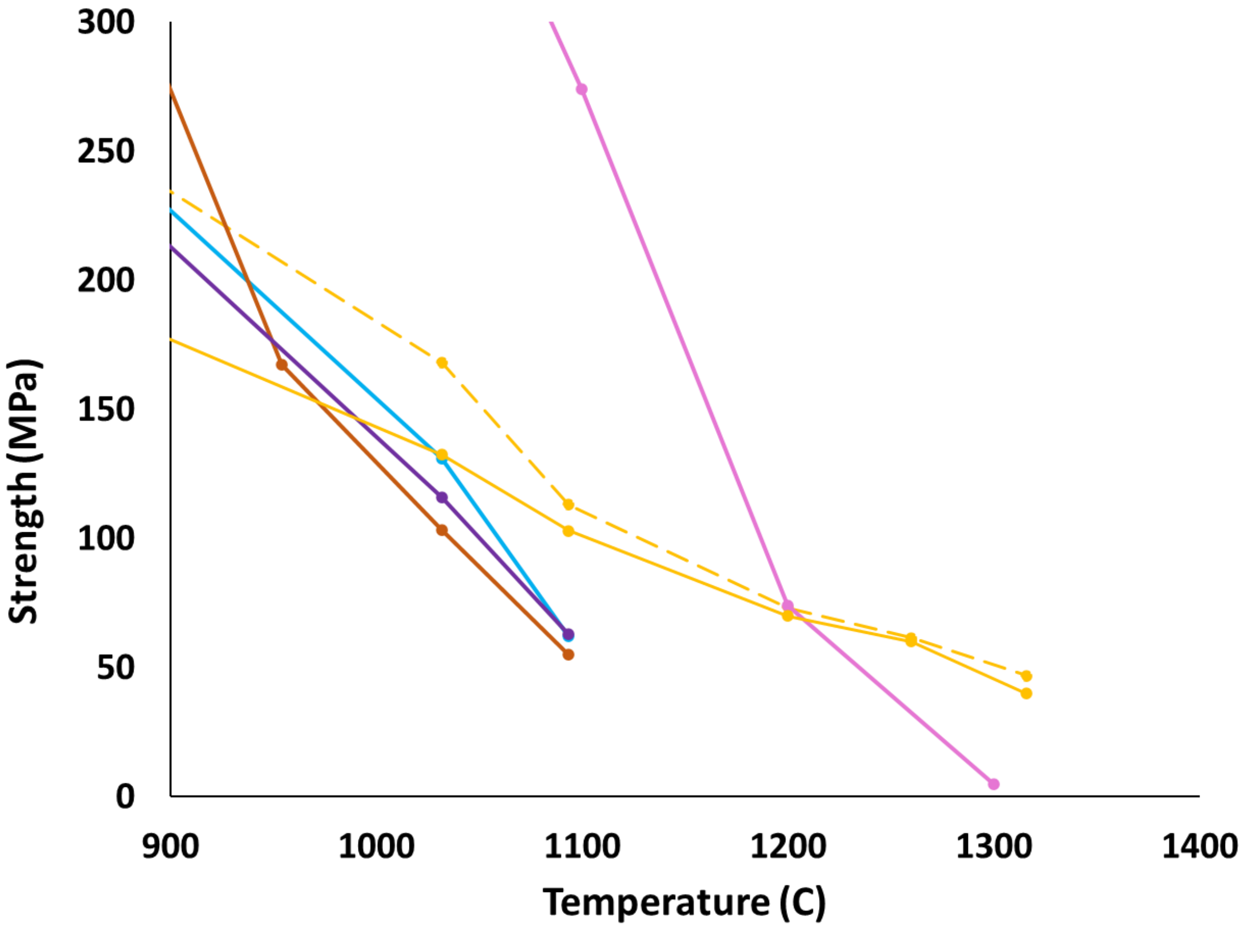
High resolution microscopy reveals dispersed nano-oxides and grain boundary Nb/Ti-rich MC Carbides.

GRX-810 Tensile Overview

Tensile Strength Comparison 1093°C



Yield Strength vs. Temperature

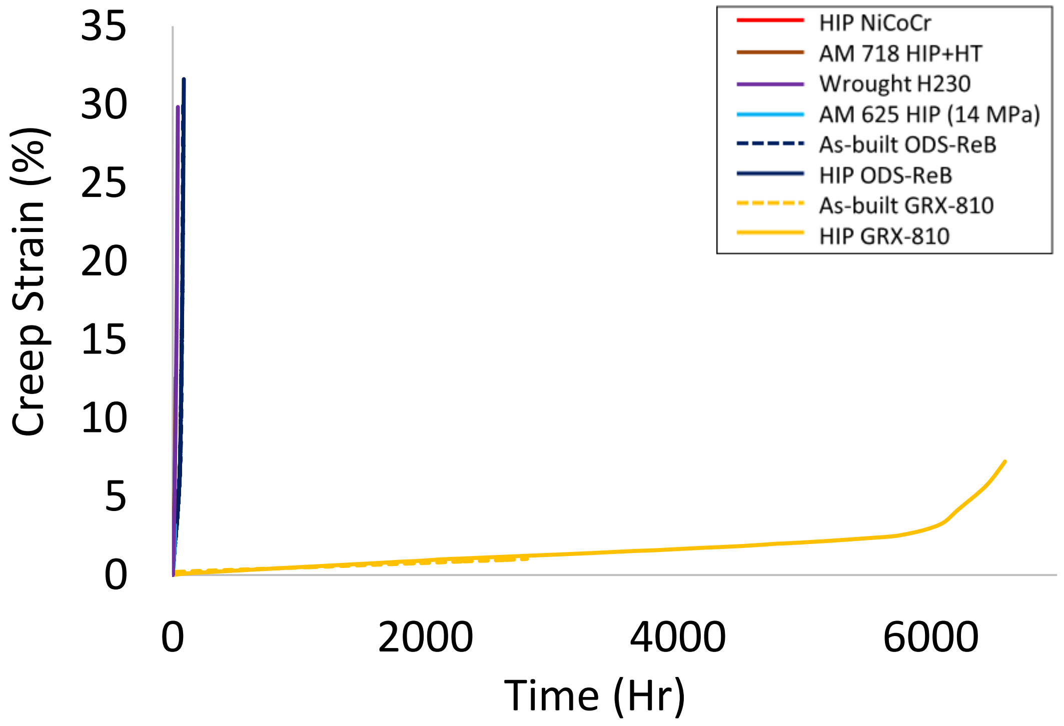


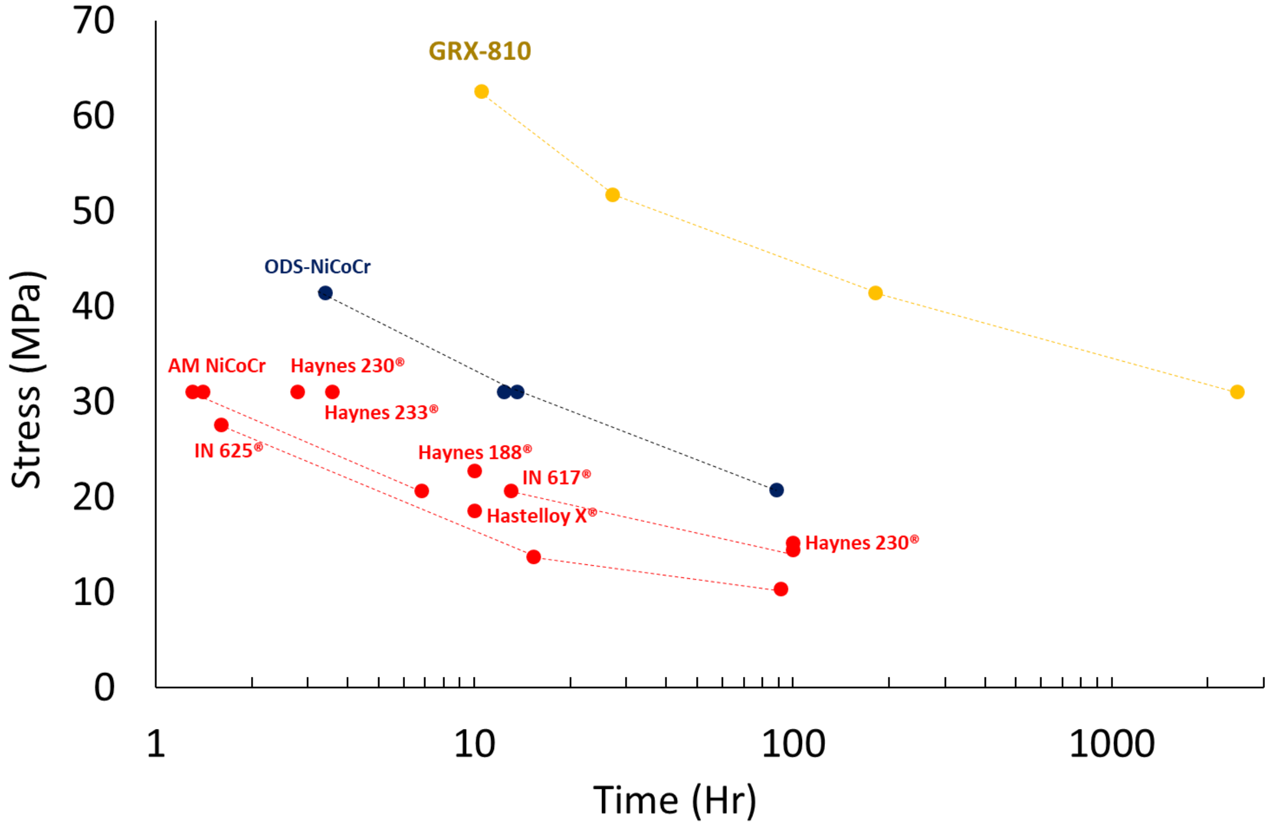
As-built GRX-810 Tensile Properties

Temperature (C)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation
-195.6	1303.1	910.1	39.6
21.1	882.5	641.2	33
426.7	710.2	527.4	33.3
648.9	675.7	479.2	32.1
871.1	292.3	249.6	56.1
1093.3	128.9	127.6	22

Above 900°C GRX-810 is stronger than most "printable" superalloys. Above 1200°C, GRX-810 is stronger than CMSX-4

Creep Rupture Lives Comparison- 1093°C

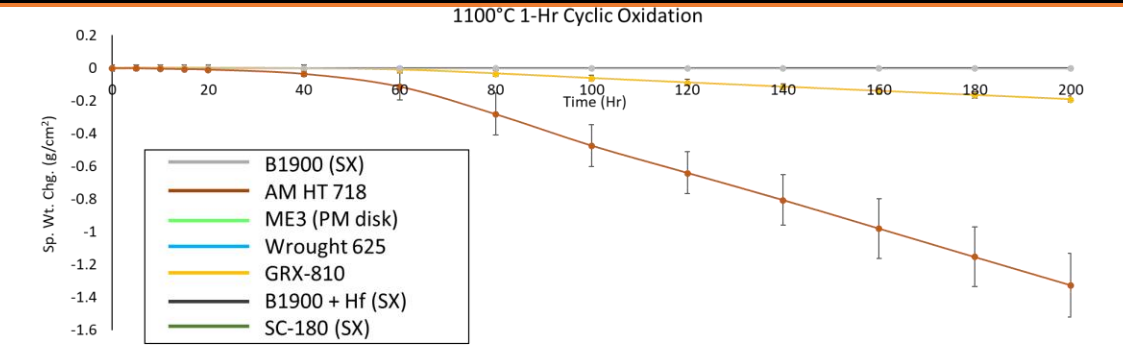


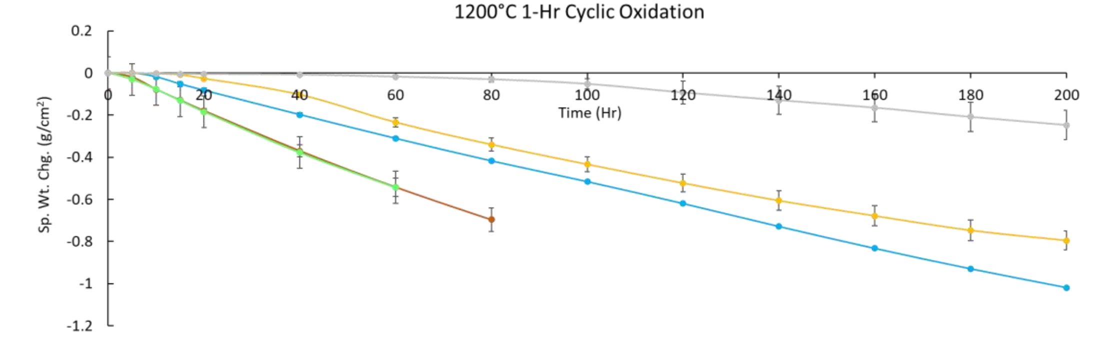


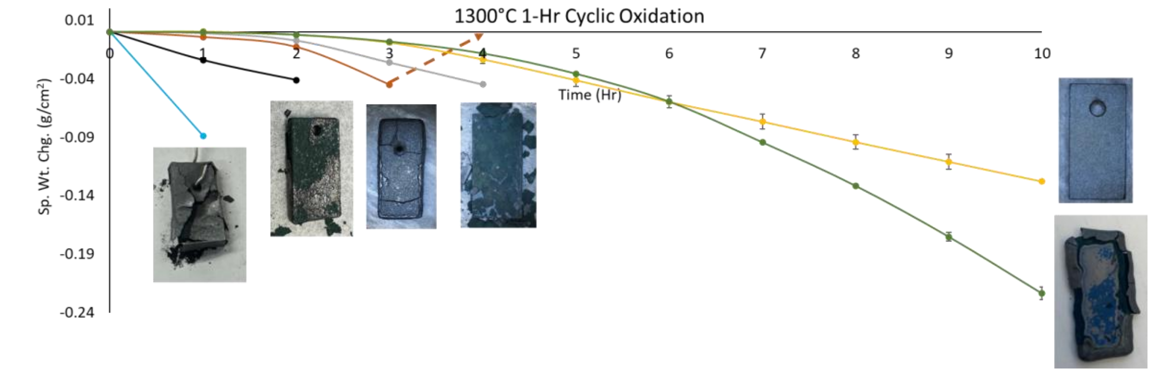
Alloy	NiCoCr	AM 718	AM 625*	Haynes 230	ODS NiCoCr	C-103 (Vacuum)	As-built GRX-810	HIP GRX-810
Time (Hr)	0.35	2.2	10	5	9	1170	2804	2122

Table: Time to reach 1 % Creep Strain at 20MPa. Note: Superalloy 625 test was performed at 14 MPa.

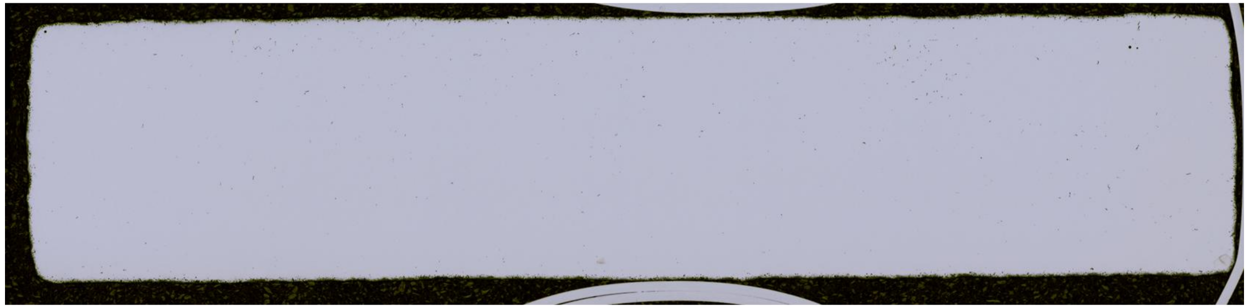
Cyclic Oxidation – GRX-810







GRX-810 – 10 cycles



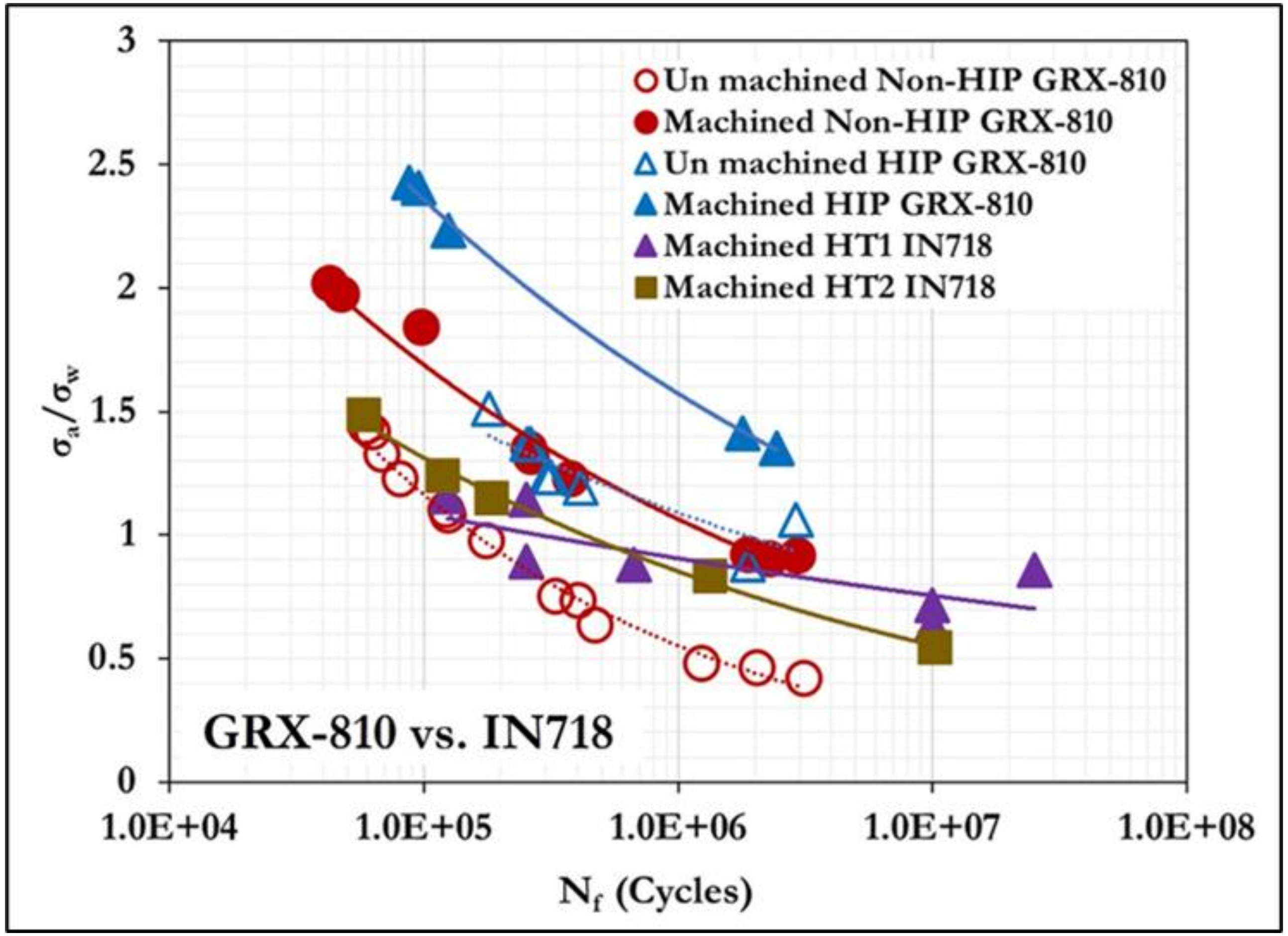
718 – 7 cycles

Above: Oxidation at 1300°C

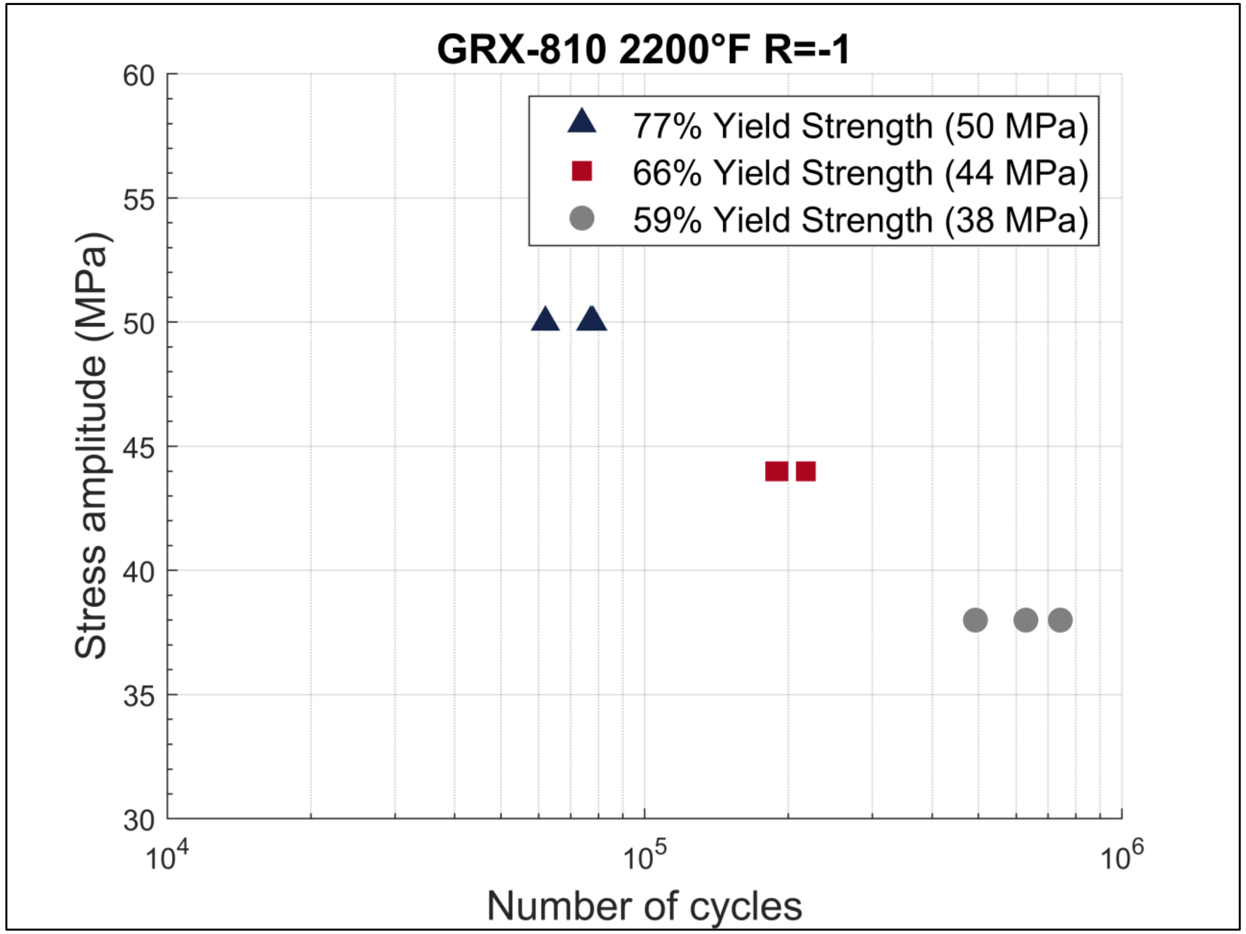
The oxidation and microstructural stability of GRX-810 is notable up to 1300°C

Fatigue Life of GRX-810

Room Temperature Fatigue Life



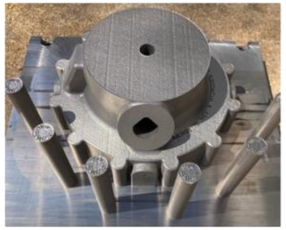
High Temperature Fatigue Life



How does it stand up in NASA applications?

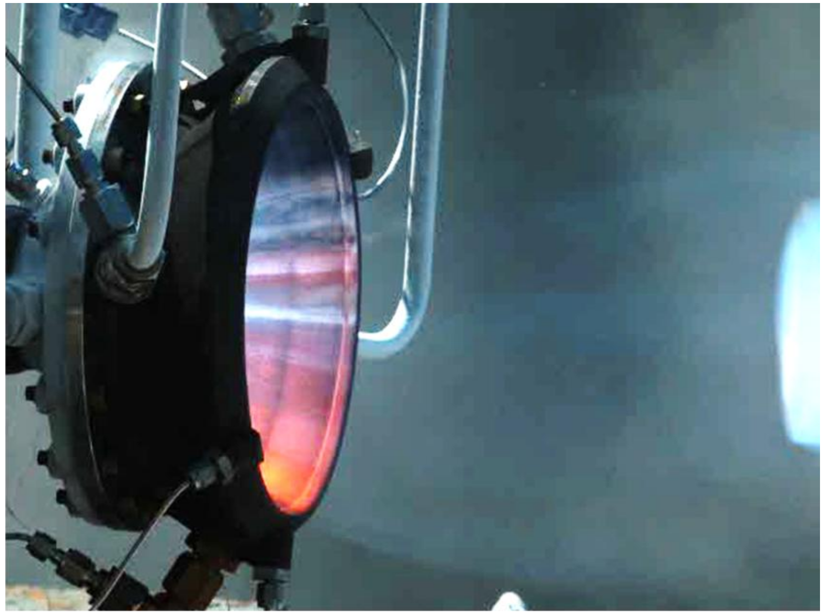
Successful Hot-fire Testing of GRX-810

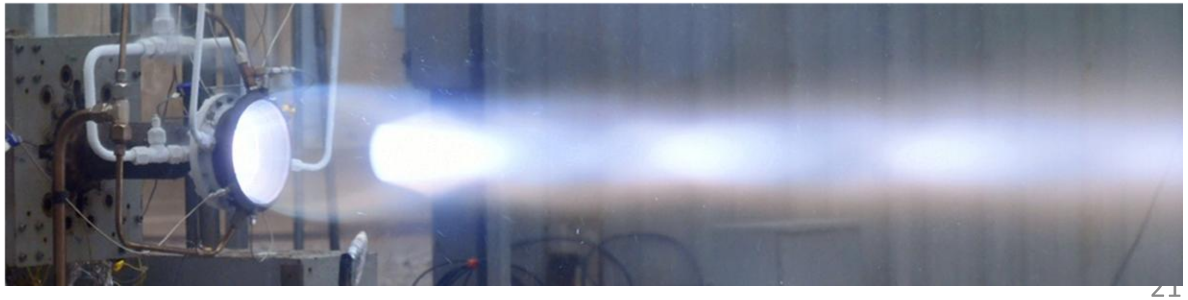
- GRX-810 is actively used for liquid rocket engine various injectors and channel-cooled nozzles L-PBF manufacturing and testing
  - Rotating detonation rocket engines
  - Lander development engines
- Propellants: LOX/LH2 and LOX/LCH4
  - Chamber Pressure ~750 psig (52 bar)
  - LOX/LH2 Mixture Ratio = 5.3 – 7.0
  - LOX/LCH4 Mixture Ratio = 2.7 – 3.6
- Demonstrate successful component fabrication process
- Challenge material at elevated temperatures in actual components
- Increase TRL from 3 → 5


Injector


As-Built Nozzle


Post-HIP Nozzle



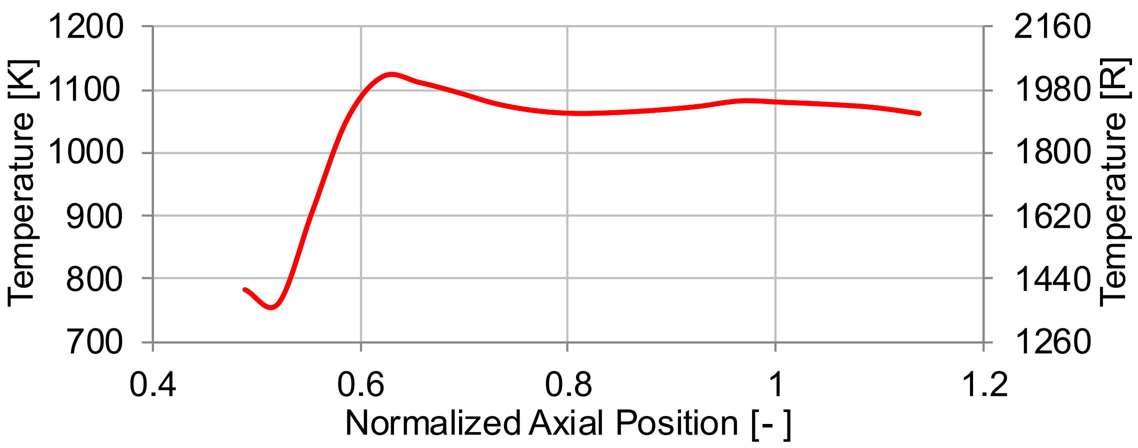


Injector Test Results

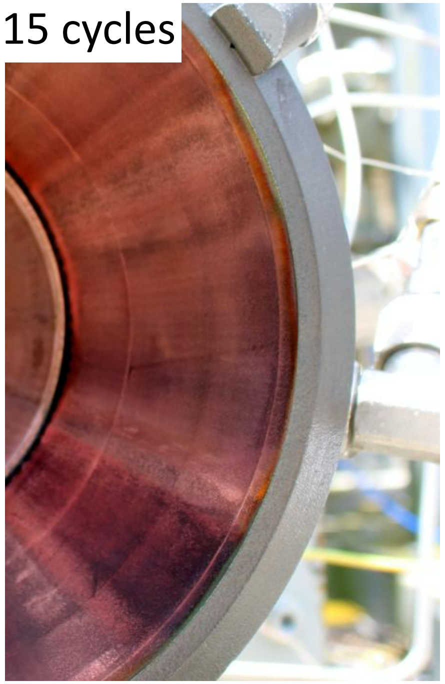
- GRX-810 Injector A achieved 84 starts and 2,228 sec (LOX/LCH4)
  - Demonstrated greater life than Inconel 625/718 equivalent
- GRX-810 Injector B achieved 30 starts and 591 sec (LOX/LCH4)
- GRX-810 Injector C achieved 9 starts and 303 sec (LOX/LH2)
- Inconel 625 injector saw heavy erosion after 10 starts

GRX-810 Component Test Results

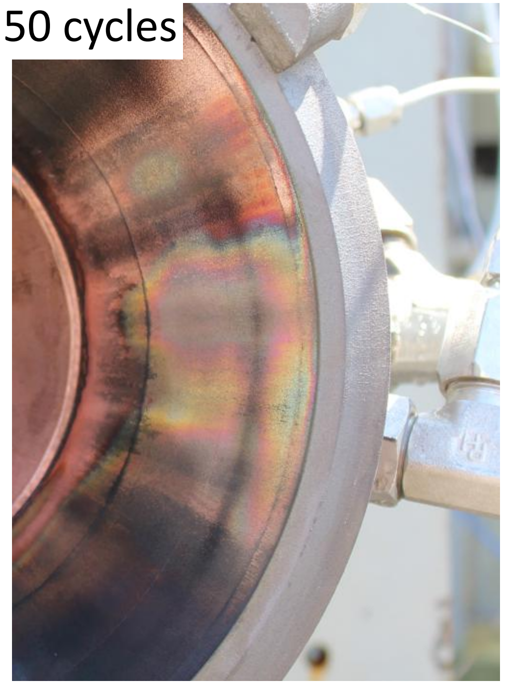
- Regeneratively-cooled (LCH4) nozzle accumulated 90 starts and 2,309 seconds.
- Local wall temperature >1,000°C
- Injector



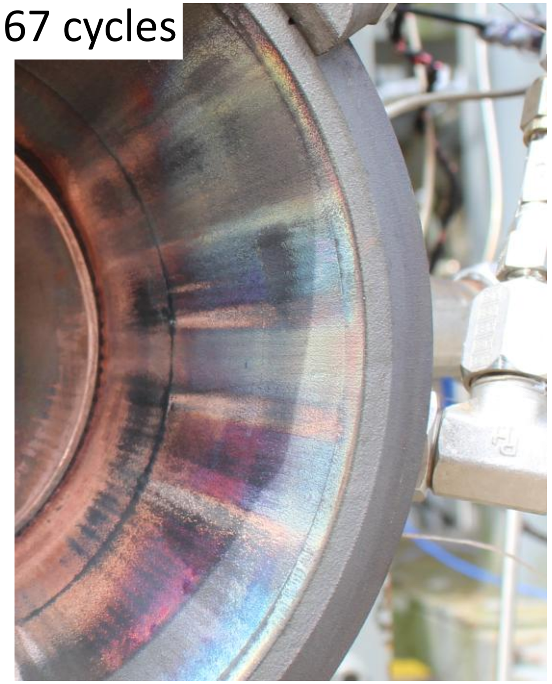
15 cycles



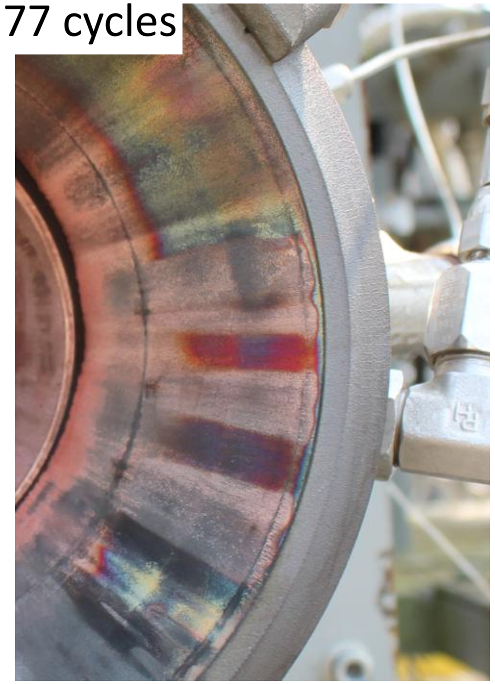
50 cycles



67 cycles



77 cycles



L-PBF GRX-810 Component Examples

Turbine Blisk Demo

Inducer with flow passages

Pentad Injector

Shrouded Blisk

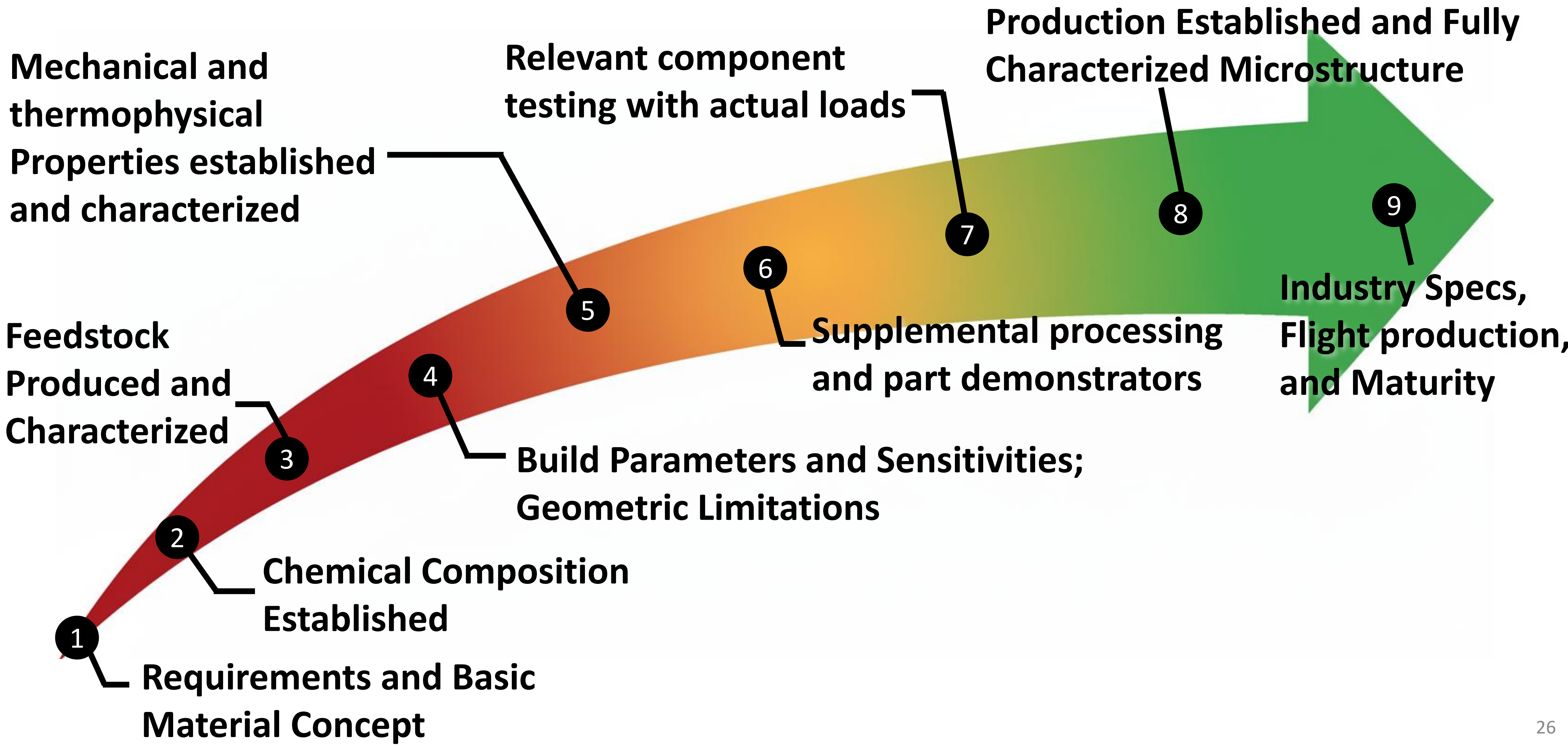
Toroidal Inducer

Regen Nozzle

Turbine Blade with integral instrumentation ports

What’s next for alloy development?

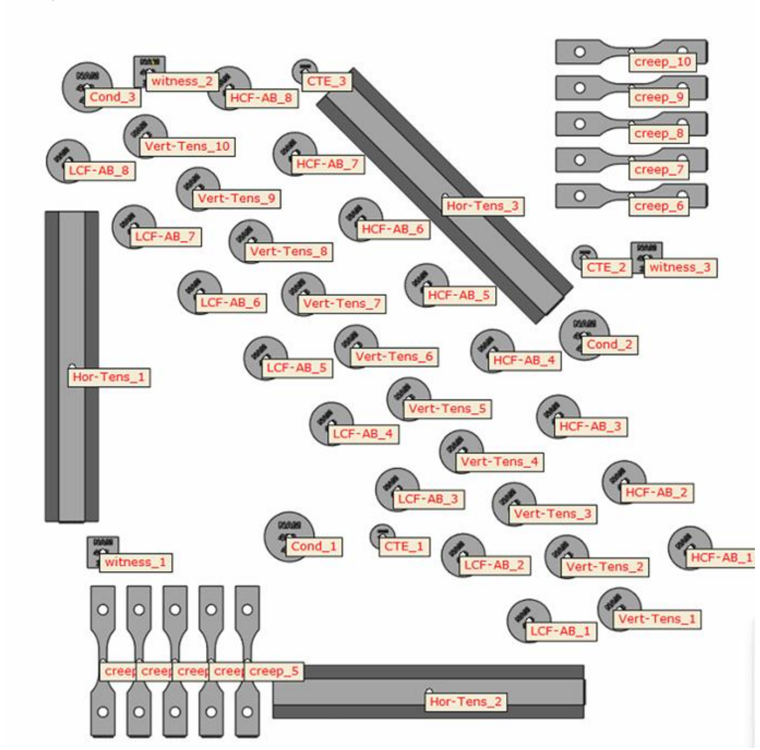
Additive Material Readiness Levels



GRX-810 Reuse and Other Studies

Material	Condition	Printer Machine	Orientation	**Recycled**	Test Temperature (F)	Number of Tests	Avg. 0.2% Yield Strength (ksi)	Avg. Tensile Strength (ksi)	Avg. Elongation (%)
NASA GRX-810 - Virgin	As-built	M400-4	Horizontal	**No**	2000	16	13.3	14.3	14.2
NASA GRX-810 - recycled	As-built	M280	Horizontal	**Yes - 25x**	2000	4	14.4	15.76	13.1

Empirical evidence suggest that GRX-810 could be recycled many times without a degradation of properties or printability.



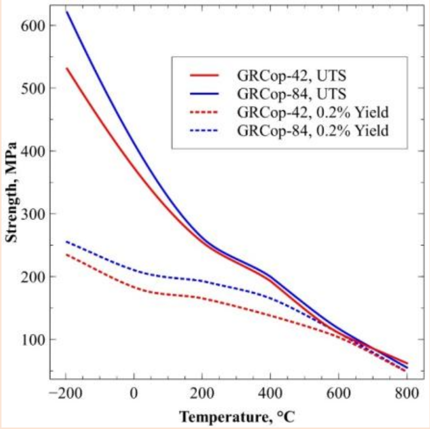
Current work: NASA is currently performing a quantitative reuse study on coated GRX-810 powder.

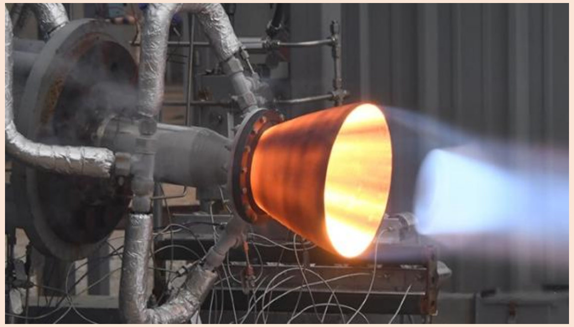
- **Left:** Build layout of the GRX-810 reuse study
- The study will explore 25 print cycles with the same powder lot without new powder additions between cycles.
- The study will record any changes in powder characteristics, defect formation, thermo-physical properties, tensile strength, fatigue, and creep.
- Currently printing cycle 15 out of 25.

Future work: NASA is currently exploring next generation dispersion alloys for a multitude of applications and environments.

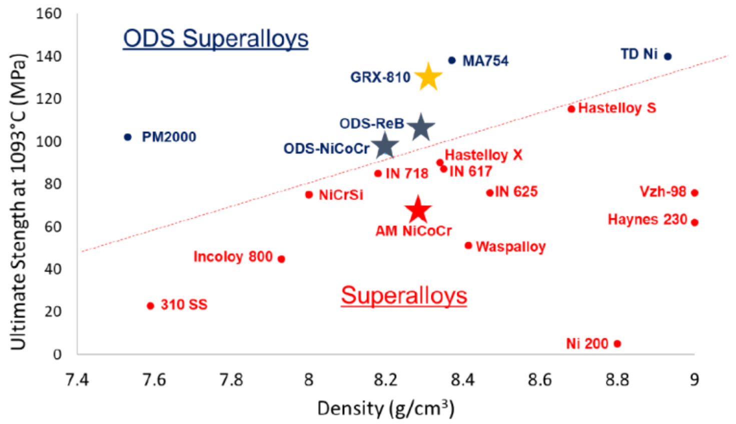
AM Enabling New Alloy Development

GRCop-42, High conductivity and strength for high heat flux applications

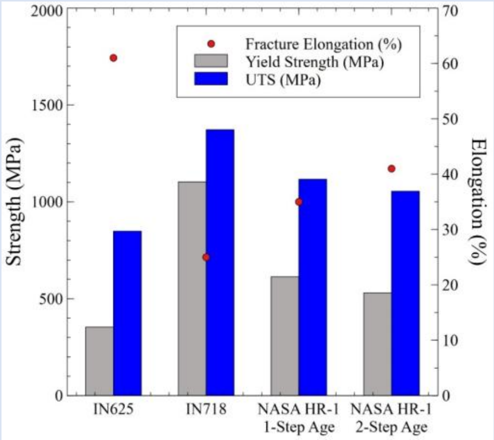


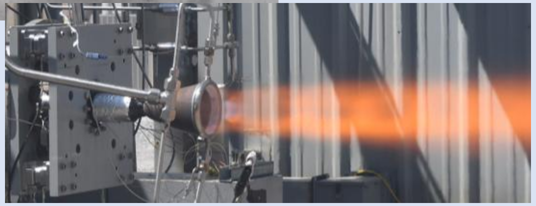


GRX-810, high strength, low creep rupture and oxidation at extreme temperatures

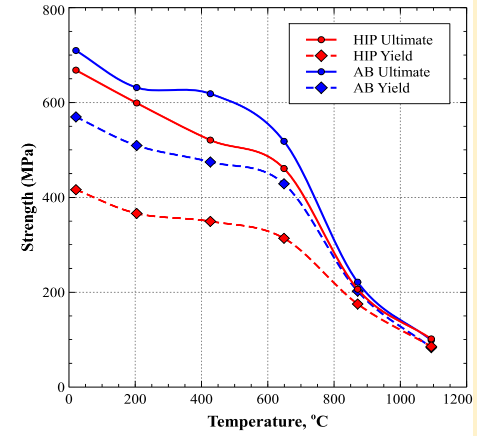


NASA HR-1, high strength superalloy for hydrogen environments





ORCAlloy-21 / Alloy 754-ODS, high strength burn-resistant alloy for oxygen-rich staged combustion



Questions?

Image from Artemis II Mission, April 2, 2026

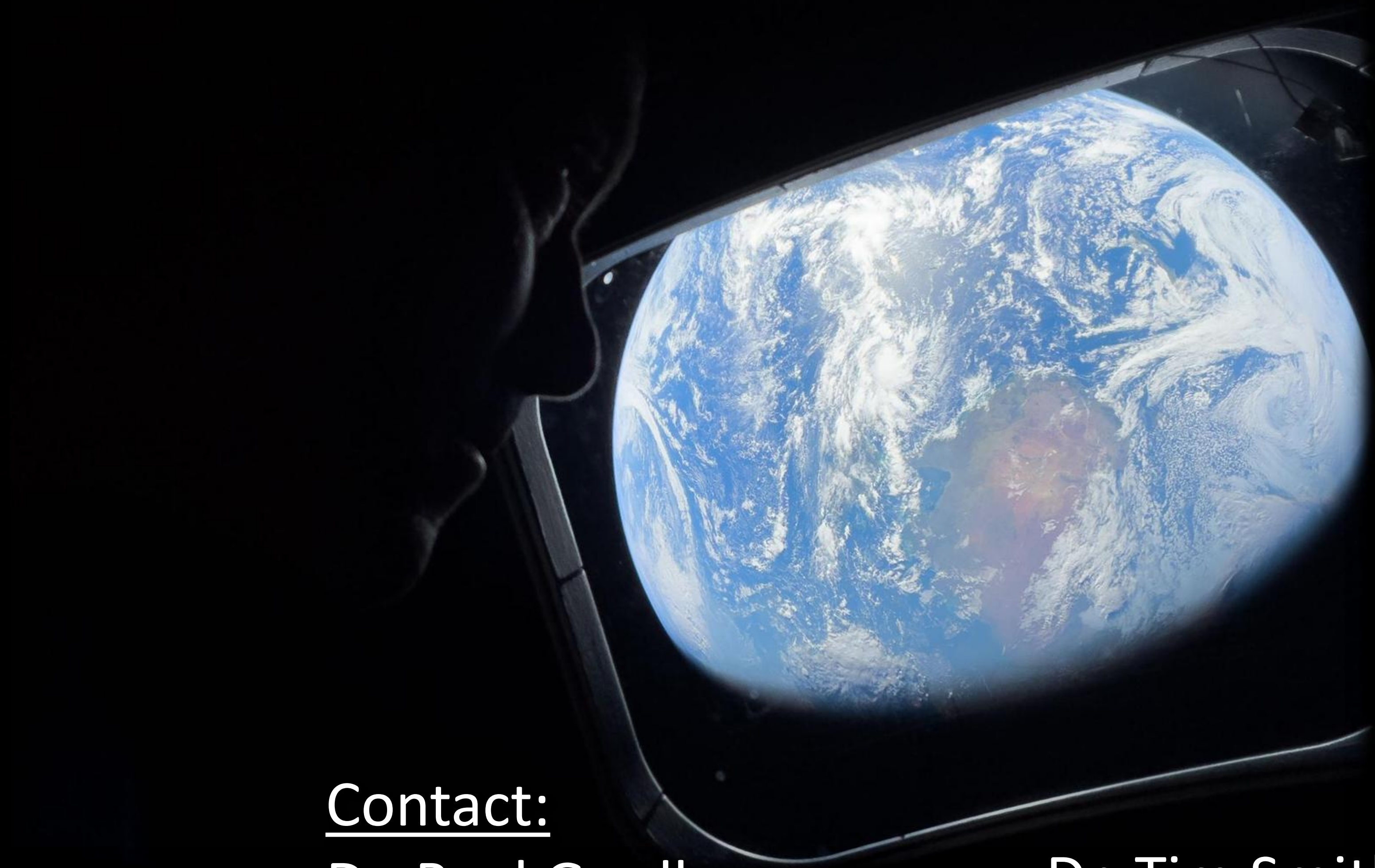


Image from Artemis II Mission, April 6, 2026

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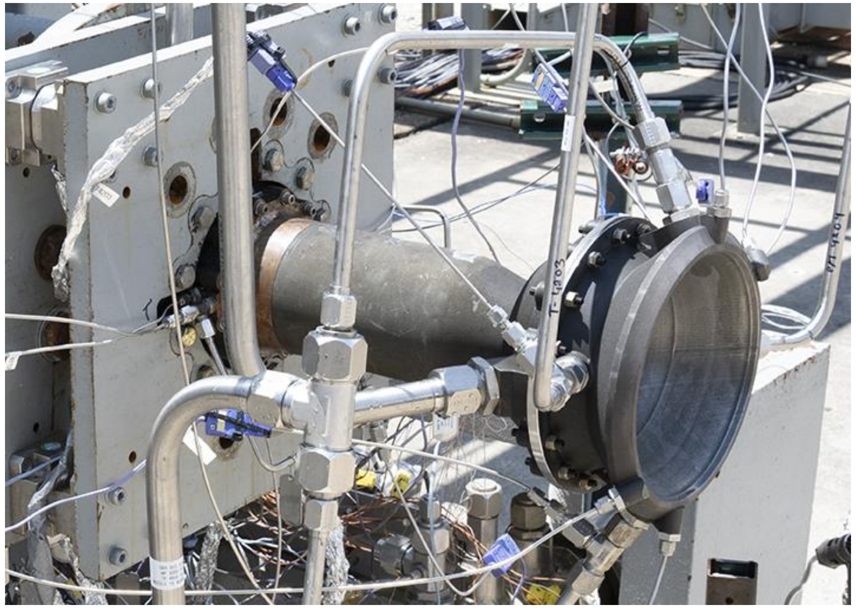
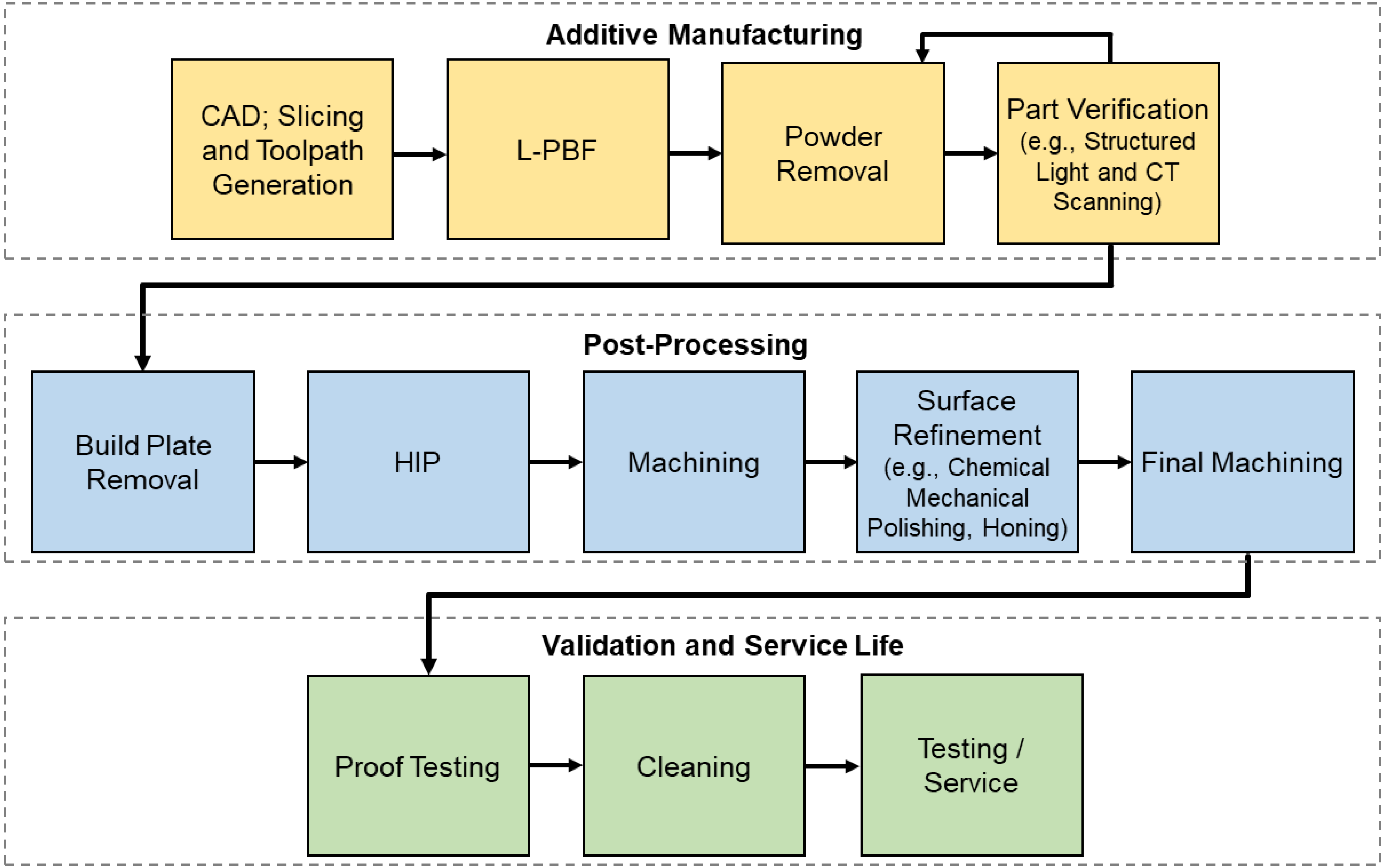
Backup

Hot-fire Testing of L-PBF GRX-810 Injector and Nozzle



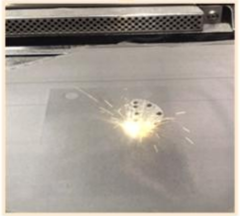
Component (-)		Starts (-)	Duration (s)	Pc (bar)	Pc (psia)	MR (-)
H2 Injector	SN01	9	302.8	49.5 - 57.2	718 - 829	5.33 - 7.02
CH4 Injector	SN02	29	586.5	37.4 - 52.4	542 - 760	3.03 - 3.65
CH4 Injector	SN03	84	2,227.9	43.2 - 52.1	626 - 756	2.68 - 3.19
Nozzle	SN04	91	2,309.4	37.4 - 52.1	542 - 756	2.68 - 3.11
Nozzle	SN05	8	149.1	49.0 - 50.5	711 - 732	3.00 - 3.19

Typical Process Flow of GRX-810 Hardware

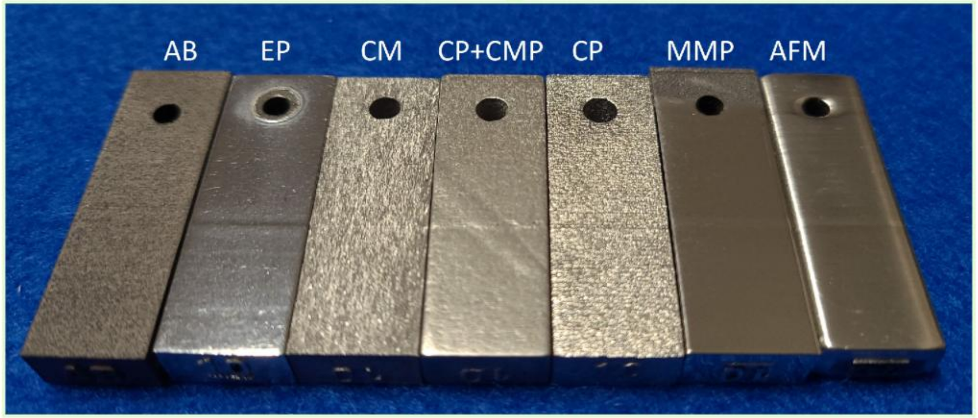


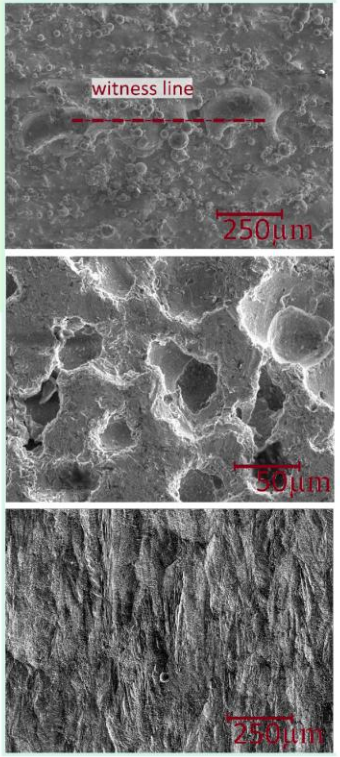
GRX-810 Surface Enhancement Development

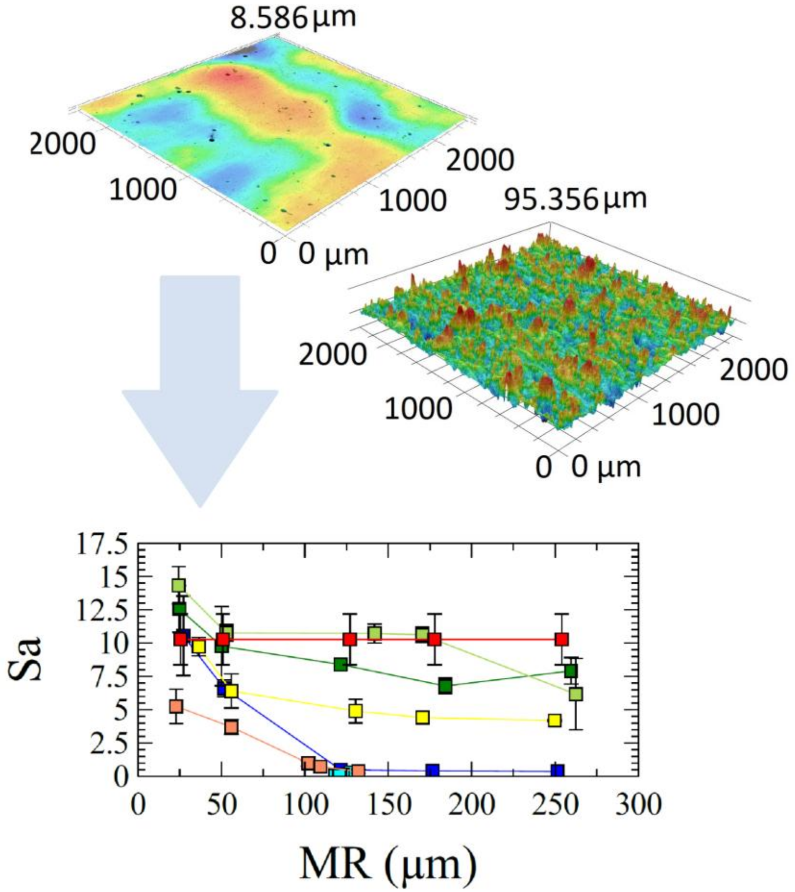
L-PBF GRX-810 → Post-Process → SEM → Surface Texture



AB: As built
EP: Electropolish
CM: Chem Milling
CMP: Chemical mechanical polish
CP: Chem Polish
MMP: Micro-milling
AFH: Abrasive flow honing







Ongoing NASA and Supply Chain Development

- Material property testing to mature publicly accessible mechanical and thermophysical data
  - Tensile and fatigue
  - Bulk properties and thin-wall studies
  - Elevated temperatures approaching 1300°C
  - Fracture toughness and crack growth
  - Oxidation studies
- Process capability geometric variations
- Process build interruption studies
- Surface enhancements and polishing
- Hot isostatic pressing (HIP) studies
- Weldability trials
- Machinability trials
- Powder recycling studies
- Powder qualification procedures
- Evaluation of laser powder directed energy deposition (LP-DED)

Summary and Future Work

- Demonstrated successful formulation, powder processing and coating, microstructure characterization, mechanical properties, component development and hot-fire testing of GRX-810 alloy.
- Successful scale up to large-scale platform and properties.
- Elevated temperature tensile (1100°C) is 2x Alloy 718.
- 1,000x improved creep rupture compared to Ni-based superalloys.
- Demonstrated successful injectors and nozzle L-PBF builds, processing, and hot-fire testing.
- Accumulated significant time and starts in actual engine conditions, increased TRL = 5